REPORTS OF OBSERVATORIES.

ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION.*

During the past year the acquisitions of property have been as follows: *Apparatus.*—Astronomical and physical apparatus has been purchased at an expenditure of $2,000. *Library and Records.*—The library has been enlarged by the addition of periodicals and books of reference at an expenditure of $200. Books and periodicals have been bound at an expenditure of $250. Total for library, $450.

The Solar-energy Spectrum.—The early work of this Observatory described in Volume I of its Annals was chiefly concerned with the minute absorption bands in the intra-red solar spectrum; automatic prismatic energy curves were made by the aid of the bolographic process, and such inflections of these curves as were found not accidental in their origin corresponded to the so-called Fraunhofer lines of the visible spectrum. Less attention was paid to the whole height of these curves at their various parts than to these numerous small variations in height.

The Absorption of the Atmosphere and of the Solar Envelope.—This present year care has been taken to obtain energy curves whose heights shall be comparable. It was the purpose of this work to study the general absorption of the sun's envelope, the general absorption of the earth's atmosphere, and the changes in the selective absorption of water vapor in the latter. It is the further object toward which these studies tend to see if the Sun is constant or variable in its output of radiation. While the results of the past year indicate possibility of considerable ultimate success in this final object, it may probably prove that the situation of this Observatory is unsuitable to the most exact studies of this kind, owing to the great and variable absorption of the air column above it, as well, of course, as to the ground tremors inherent in its present site,

* Condensed, with permission, from "Report of the Work of the Astrophysical Observatory for the year ending June 30, 1902, by C. G. Abbott, *Aid Acting in Charge.*"

surrounded by the traffic of city streets. It seems certain, however, that valuable contributions to the methods of study to be adopted in work at more favorably situated stations, and to the knowledge of terrestrial absorption, can be made here.

Absorption of the Atmosphere and Selective Absorption of Water Vapor.—Since January 20th all favorable opportunities have been used to take quick-speed energy curves. These have been made with quite different altitudes of the Sun. Sometimes as many as 15 have been taken in one day, and 160 were secured between January 20th and July 1st. These curves are studied from two points of view: first, as regards the variation in height for single wave-lengths with different altitudes of the Sun; second, as regards the variation in area and especially the areas of the great regions of water-vapor absorption. The first kind of examination leads to the determination of the general absorption of the air, the second to fixing the variations in amount of the solar radiation and of the special selective absorption of water vapor.

To illustrate the first method of study, let us suppose several energy curves to have been taken in a single clear day, during which the barometer height was (B), and let (B_o) be the standard barometric height, generally taken as 76^{cm}. From the altitudes of the Sun as computed from the hour angles and declination, the air mass (m) is determined. This quantity represents the ratio which the mass of air traversed by the solar beam bears to that mass of air which would be traversed if the Sun was directly overhead. If we suppose (e) to represent the amount of radiant energy per square centimeter of a certain wave-length which reaches the Earth's surface, and (e_0) the amount prior to absorption by the Earth's atmosphere, and let (a) be the proportion transmitted per unit air mass, then by the well-known formula of BOUGUER:—

$$e = e_o a^{m \frac{B}{B_o}}$$

But since the height (d) of the bolographic energy curve at the wave-length in question is proportional to (e), we may write:

$$d = ke = ke_o a^{m \frac{B}{B_o}}$$

where (k) is an instrumental factor connected with the width

of the slit, the absorption of the optical surfaces, the quality of the bolometer, and the sensitiveness of the galvanometer. We may assume (e_0) and (k) to be constant for the short space of time occupied by one day's observations. We then obtain the following equation:—

$$\log (d) = m \frac{B}{B_0} \log (a) + \log (ke_0)$$

of which the last term is constant. This equation is in the form of the equation of a straight line, so that if we make a plot in which heights are proportional to logarithms of (d), and horizontal distances to values of ($m \frac{B}{B_0}$), the various observations should determine a straight line the tangent of whose inclination is the quantity log. (a). The procedure has been followed with many of the energy curves already taken.

Absorption of the Solar Envelope.—The experiments on the absorption of the solar envelope briefly mentioned in last year's report were continued as far as practicable with the apparatus available.

Personal-equation Machine.—You* have placed at the Observatory for trial an instrument of your own design intended to eliminate the so-called personal equation of individual observers in transit observations. The principle of this instrument consists in substituting a judgment of the place where a sudden phenomenon occurred for the time when it occurred. To use an illustration which you have already employed, in case the dark field in which only the star is seen moving were illuminated every two seconds by a self-recording flash which showed the central wire, and if by pure accident the star was caught in an exact bisection when the flash came—an accident against which the chances are perhaps more than a hundred to one—it is evident that in this rare and improbable event there would be no personal equation to allow for, if the time of flash within two seconds were noted by the observer. Now, the object of the following mechanism may be said to be to make this accident happen every time.

This being understood, as first tried with the apparatus which you furnished, the design was to illuminate the cross-

* This report is addressed to Professor S. P. LANGLEY, Secretary of the Smithsonian Institution.

wires of the transit instrument by automatically recorded electric flashes occurring at regular intervals equal to the time elapsing between passages of the star across successive wires. An adjustable mechanism allowed the observer to hasten or defer the whole system of flashes until by successive adjustments he caught the exact instant when the star was bisected by the dark wire in the instantaneously bright field. Several such adjustments could be made during a single star transit across the numerous wires of the tally, and immediately after each satisfactory bisection a signal was made on the chronograph by a key in the hand of the observer, so that only such recorded flashes as were thus distinguished were used in determining the time of transit.

In order to test the value of this instrument an artificial star was caused to move through the field at a rate about equal to that of a real equatorial star. This star was moved by a screw and clockwork of great accuracy, and always through the same portion of the screw. It was also provided that when the star was exactly bisected by the middle wire an electrical contact was broken, so that the star recorded its own transit upon the chronograph. The adjustment of the contact for this bisection was made at leisure with the star stationary, and was therefore not subject to the personal error of transit observations. Accordingly, after determining all the wire intervals, it was entirely easy to measure the personal equation of the observer, whether he used the personal-equation machine or the ordinary method, merely by comparing his observed time of transit with that recorded by the star itself. Upon trial it was found that the personal equation of the several observers was not wholly prevented by employing the machine in the manner described; that is, by bisections judged during instantaneous flashes. The writer, for example, observed about 0.12 second too early by both methods.

It seemed probable that the observer was still biased in his judgment by watching the march of the star through the field across the very faintly showing wires, which are always to be made out by the stray light of the star and sky, even though there is no illumination by the flash. Accordingly it seemed to promise success to alter the arrangement so that the star would be hidden except at the instants corresponding to those when

the flash had formerly appeared, and to steadily illuminate the field as is usual in transit instruments. In the test this was easier than in actual practice, for the artificial star itself could be obscured by a shutter immediately in front of it, which could be removed instantaneously by the electric signal from the personal-equation machine. The same thing could, however, be done at the focal plane of the telescope in real use.

Upon trial this device justified all hopes. Three observers whose habit is to observe, one too early, one too late, and the other very close to the true time, were found all to observe as close to the truth as the accidental errors would admit, which in the case of the 3-foot focus transit instrument employed was generally within 0.03 second. In other words, personal equation seems to be wholly eliminated by this procedure. The general design may be applied without great expense to any outfit of transit and chronograph.

Experiments on "Boiling" of the Image.—I add a few words, partly in anticipation, in reference to your newly-introduced device for preventing the well-known effect of "boiling" of the telescopic image, a difficulty due to the Earth's atmosphere and which has existed always and everywhere, and which has seemed until lately so insurmountable that it has not even been thought of as subject to correction. The device that you have suggested consists essentially not in keeping the air still within and without the telescope tube, but in violently agitating it over as great a range as possible. For this purpose, under your instructions and with the object of rehearsing on a small scale what, if the device is successful, will be later tried on a large one, a silvered-glass mirror of five inches diameter and forty feet focus has been set up in a tube with several concentric walls, so as to leave the interior air as still as possible. In preliminary experiments the air, in spite of these precautions in the installation, gave such "boiling" of the image as to seriously prejudice the definition, and this, although the forty-foot tube had no less than three walls, being seven inches in interior diameter and fifteen inches in exterior diameter, and inclosing the beam all the way from a second plane mirror near the cœlostat to the concave mirror and thence to the focus. Though this tube containing the stillest air of the most uniform temperature was sheltered throughout by a canvas tent, the "boiling"

was but a little diminished. Nothing was gained by diminishing the aperture of the several mirrors down to one inch in diameter, and all this was only what had been anticipated from the ordinary experience of astronomers. A twelve-inch blower run by an electric motor was now caused to exhaust air from the inner tube at a half-dozen points along the tube, and to force air in at other points alternate with these, so as thus violently to disturb or "churn" the air by forcing a vigorous circulation of it along the whole path of the beam from the cœlostat to the solar image. This unquestionably reduced the "boiling." An artificial star was now provided at the focal plane, the plane mirror near the cœlostat was placed at right angles to the tube, and thus the concave mirror, acting as both collimator and objective, brought the star-image to focus at the star itself. Here it was examined with an eye-piece. With still air the definition was often very poor. The image assumed very variable shapes, with wings or streamers; and being also colored by diffraction effects, reminded one of a kaleidoscope field. On starting the blower the definition immediately became sharp. Violently stirring the air in the tube, therefore, eliminates the "boiling" within the tube and (paradoxically) produces a still image. As before said, the solar image was clearly improved by the stirring; but further improvement was still to be desired. Accordingly a tin tube forty-four feet long, with two walls of eleven inches interior diameter and sixteen inches exterior diameter, was provided and arranged to point toward the Sun, so that the beam passed down through it before reaching the mirror system. This tube was connected to the blower exactly like the horizontal one, and both could be stirred at once. There was a very marked "boiling" before starting the blower. This nearly disappeared while the blower was running. One observer estimated the "boiling" as four-fifths overcome; another thought little more than a quarter remained, and all were unanimous that what was left was very little prejudicial to the definition. This last result is so surprising that I feel constrained to add that the experiments so far are not exhaustive, having been carried on but a short time, and without that solidity of piers which would allow of exact estimate or photographic determination of the "boiling" of the solar image before and during agitation of the

air in the tube, as distinguished from mechanical jarring. Further experiments are in progress. That agitation is of very great advantage to diminish "boiling" there is no question, but the exact measure of the advantage for all circumstances of bad seeing requires further study. Incidentally, the air blast has the added advantage of keeping the mirrors at uniform temperature. This and the abolishment of "boiling" in the tube are found to prevent those vexatious changes of focus so common in solar work.

Radiation of the Cuban Firefly.—In continuance of your observations on the cheapest form of light, two specimens of the Cuban firefly were loaned by the Agricultural Department. The radiation of the thoracic-light regions of these insects was briefly studied by the aid of the bolometer and photometer. A comparison of the light and heat of the standard sperm candle with that of the firefly showed the latter to be more than 10,000 times more economical as a source of light.

Personnel.—The observing-staff has been unchanged with the following exceptions: Dr. C. E. MENDENHALL was employed as temporary assistant up to August 3, 1901, and Dr. N. E. GILBERT as temporary assistant, beginning June 16, 1902.

LEANDER McCORMICK OBSERVATORY OF THE UNIVERSITY OF VIRGINIA.

ORMOND STONE, DIRECTOR

Among the recent researches undertaken at the Leander McCormick Observatory, is an investigation of the standards of faint stellar magnitudes in co-operation with the Harvard, Yerkes, and Lick observatories, to be followed by a study of the more important long-period variables. The former work was done principally by Mr. H. D. CURTISS (Ph. D., 1902), now of the Lick Observatory; in the latter Professor STONE is assisted by Mr. PADDOCK, one of his present students.

LOWELL OBSERVATORY, FLAGSTAFF, A. T.

A little more than a year ago, an efficient modern spectrograph, designed and built by JOHN A. BRASHEAR, of Allegheny, Pa., was added to the equipment of the observatory. The attachment of this instrument to the twenty-four-inch refractor

necessitated the enlargement of the dome. This work was begun in December, 1901, and completed in March of the following year. During this period, when possible, the telescope was used in measuring star-disks.

Since that time, after the completion of the adjustments of the spectroscope, the twenty-four-inch refractor was devoted to the photographing of stellar spectra for motion in the line of sight, until August. Since then, the time has been divided between stellar and planetary work. Successful spectrograms have been obtained from *Uranus, Jupiter, Saturn, Mars, Venus,* and the asteroid *Vesta.*

During the last part of the year considerable time has been given to visual observation of planets, chiefly *Mars.*

January 31, 1903. V. M. SLIPHER, *for Observatory.*

THE CHAMBERLIN OBSERVATORY OF THE UNIVERSITY OF DENVER.

During the first six months of 1902 no observations were made with the twenty-inch telescope, because the time of the observers was otherwise filled. But some minor repairs and alterations were made in the instrument.

In July Dr. CHARLES J. LING began a search for *Eros,* which culminated in its visual rediscovery early in August. From September on observations of comets and of *Eros* have been made.

February 7, 1903. H. A. HOWE, *Director.*

GOODSELL OBSERVATORY OF CARLETON COLLEGE, NORTHFIELD, MINNESOTA.

The research work of this observatory is at present devoted almost exclusively to solar and celestial photography. A few micrometric observations of double stars and comets are made with the sixteen-inch refractor on nights unsuitable for photography. Daily photographs of the Sun have been taken whenever possible since 1889. The approximate measures of the photographs taken from 1889 to 1893 were published last summer in *Publication* No. 3 of Goodsell Observatory.

There are on hand something like 1,200 solar photographs taken since 1893, which have not been measured because of the

lack of the necessary funds for assistance, the time of the two professors being fully occupied with their duties in the instruction of the college classes, and the work of editing "Popular Astronomy."

So far as his strength would permit, Professor WILSON has given his time on the moonless clear nights to long-exposure photographs with the eight-inch Clark refractor, the six-inch Brashear star-camera, and the 2½-inch Darlot camera. These three instruments are on the same mounting and are guided by means of a five-inch telescope fastened rigidly to the eight-inch and of the same focal length with it. Most of the photographs have been of four or eight hours' exposure, the latter requiring two nights. The most successful one of the *Andromeda Nebula* received twelve hours' exposure, requiring four nights' work. The longest attempted exposure with the eight-inch was one of seventeen hours on the *Pleiades,* which failed because of imperfect backing of the plate, but the details shown on parts of the plate showed that the limit of useful exposure with this instrument had by no means been reached. With the smaller instruments the exposure has seldom been prolonged beyond eight hours, and that with the 2½-inch lens was usually stopped with one night, its construction being such that there was danger of shifting the plate on inserting the slide. A number of the photographs taken with the cameras indicate the existence of large regions of very faint nebulosity, those covering large portions of the constellations *Orion, Taurus,* and *Scorpio* being the most notable. They are so faint that very careful development is required to bring them out upon the plates, and prints can be made only from intensified copies. They require, too, the most transparent atmosphere.

During the past six months our time for research work has been devoted wholly to the measurement and reduction of the photographs of *Eros* taken during the parallax campaign of the winter 1900-1901. By the aid of a grant of $300 from the Gould Fund and the loan of the Repsold measuring-machine belonging to the University of Minnesota, we were enabled during the summer to measure sixty-six out of the seventy-four *Eros* plates, the others being too defective for measurement. The number of comparison-stars, of the list published in circulars numbers 8 and 9 of the "Conference Astrophoto-

graphique Internationale," found upon each plate within the range of good definition, varied from five to ten. Both coordinates were measured, in two opposite positions of the plate. Six plates taken during the week November 7-15th were measured a second time, with a list of comparison-stars furnished by Mr. ARTHUR R. HINKS, of Cambridge Observatory, England. For these plates the comparison-stars numbered twelve to fourteen each. These measures are to be used by Mr. HINKS in a special determination of the parallax from the measures at many observatories during that one week.

The work of reduction goes on very slowly in connection with our regular duties, but the measures of ten plates have already been reduced provisionally. These ten are rather poorer than the average, but the results obtained show that they were worth measuring.

The probable error of the measurement of a single image of a star on one plate comes out about 0".20, and from the mean of four or five images about 0".12, while the probable error of the center of the plate from all the stars is usually below 0".10. The Declinations, as a rule, come out better than the Right Ascensions, the residuals being only from half to two thirds as great in the former as in the latter. This difference is probably due to the slight elongation of the images in consequence of the imperfect driving of the clock. On the best of the plates the images are perfectly round over two thirds of the diameter of the field,—*i. e.* over a circle with a radius of forty minutes of arc. The probable error of a single measure on these is about 0".11 and that of the center of the plate from all the comparison-stars is from 0".04 to 0".07.

March, 1903. WILLIAM W. PAYNE, *Director.*

YERKES OBSERVATORY, WILLIAMS BAY, WIS.

When the Yerkes Observatory was dedicated in October, 1897, its equipment consisted of the forty-inch refractor, with one or two accessories, and the instruments which had formerly belonged to the Kenwood Observatory. It was necessary to supply a complete series of accessory instruments for use with the forty-inch refractor, and a numerous collection of other instruments required for the varied purposes of a large ob

servatory. As funds were not available for this purpose, it was decided to provide a well-equipped instrument-shop, in which the necessary instruments could be constructed. The considerable time required to bring into effect the plan of investigations prepared when the observatory was under construction has been due in large extent to the necessity of constructing the instruments one by one with the limited means available for the purpose.

At the end of 1901 the equipment was fairly complete, though some of the more important instruments had not been finished. During the year, covered by this report (1902), however, several new investigations requiring special equipment have been undertaken, and the present programme of research represents most of the investigations originally proposed. The further additions which the provision of new funds and the completion of new instruments should render possible during the coming year, will complete the original programme.

Staff.—The staff of the Yerkes Observatory is at present constituted as follows: GEORGE E. HALE, Professor of Astrophysics and Director (solar, stellar and laboratory spectroscopy); S. W. BURNHAM, Professor of Practical Astronomy (double stars); E. E. BARNARD, Professor of Practical Astronomy (micrometric observations, stellar photography, etc.); EDWIN B. FROST, Professor of Astrophysics (stellar spectroscopy; velocities in the line of sight); G. W. RITCHEY, Instructor in Practical Astronomy and Superintendent of Instrument Construction (photography of nebulæ, star-clusters, etc.); FERDINAND ELLERMAN, Instructor in Astrophysics (solar and stellar spectroscopy, and general photography); STORRS B. BARRETT, Secretary and Librarian (solar spectroscopy); WALTER S. ADAMS, Assistant (stellar spectroscopy; velocities in the line of sight) J. A. PARKHURST, Assistant (photometry and stellar spectroscopy); N. A. KENT, Assistant (laboratory spectroscopy); J. A. JOHANNESEN, Instrument Maker; O. F. ROMARE, Machinist; F. R. SULLIVAN, Engineer in Charge of 40-inch Telescope and Night Assistant; F. G. PEASE, Optician.

Double Stars (Professor BURNHAM).—Up to the end of 1899 Professor BURNHAM was engaged in measuring all stars of short period, and others for which observations were lacking, for use in his "General Catalogue of 1290 Double Stars," which

appeared in 1900 as Volume I of the *Publications of the Yerkes Observatory*. Since that time he has confined his attention to a carefully selected list of stars, consisting mainly of long-neglected and little-known pairs. Many of these, taken from the catalogues of Sir WILLIAM HERSCHEL, Sir JAMES SOUTH, and other astronomers at the end of the eighteenth and beginning of the nineteenth centuries, have never been observed since that time. The list also includes many pairs recorded in various journals and observatory publications during the last fifty years which have been insufficiently observed or not measured at all. Among the other neglected pairs are those in which the evidence of decided change is of a somewhat doubtful character. These have been reobserved, and the supposed change shown to be real in some instances, but due to errors of observation in others. For special reasons some of the Σ and β stars have been measured, with others from the Astronomische Gesellschaft catalogues. Altogether some 600 of these objects are given in a paper which will appear soon in Volume II of the *Publications of the Yerkes Observatory*. As Professor BURNHAM's object has been to avoid duplicating work done elsewhere, he has placed no star on the working-list which would be likely to be measured at any other observatory.

General Micrometric Observations (Professor BARNARD).—Professor BARNARD has continued his work on the satellite of *Neptune*, which he has had under observation for several years. He has also obtained several valuable series of measures of the fifth satellite of *Jupiter*. His measures of 61^1 *Cygni*, for the purpose of redetermining its parallax and testing the conclusions of WILSING, were continued during the year and are now in process of reduction. Professor BARNARD's most extensive investigation with the forty-inch refractor has been a systematic micrometrical survey of between 600 and 700 small stars in the globular clusters *M* 3, *M* 5, *M* 13 and *M* 92. In the course of this work he has compared his measures of a large number of stars in *M* 13 *Herculis* with Professor SCHEINER'S measures of the same stars, made on photographs taken at Potsdam in 1891. The comparison shows that the photographic and visual measures in general agree very closely, though there are a few discordances, amounting to one or more seconds of arc. Apparently these are not due to motion in the stars, but

rather to the difficulty of making the photographic measures in the case of defective images. In the period of ten years there does not appear to be any certain proof of motion in any of the stars under observation. In the course of the work on clusters Professor BARNARD has given special attention to some of the variable stars in *M* 5 *Libræ*, for which he has determined accurate periods. In addition to the work here mentioned, Professor BARNARD has done a large amount of miscellaneous work with the forty-inch telescope, including micrometric observations of planetary nebulæ; a few double stars, such as *Procyon;* determinations of the position and focus of *Nova Persei*, etc. The measures of the *Nova* gave no evidence of a parallax. Up to August, 1902, long after the spectrum of the *Nova* had changed to that of a planetary nebula, it was found to have the same focus as that of a neighboring star. The change of focus, which was noted in September, 1902, has been described in the *Astrophysical Journal.*

Velocity of Stars in the Line of Sight (Professor FROST and Mr. ADAMS).—The Bruce spectrograph, which was completed in the instrument-shop of the observatory early in 1902, has given most satisfactory results. None of the difficulties encountered with the old three-prism spectrograph have appeared in the new instrument, and the degree of precision fully equals, if it does not surpass, the highest reached elsewhere. The twelve lunar spectra photographed during the year, for the purpose of testing the adjustment and trustworthiness of the spectrograph, gave a mean difference of 0.2^{km} per second between the observed and the computed radial velocity of the Moon, the largest difference being 0.7^{km} per second. The titanium spark was chiefly used for furnishing the comparison spectrum, but the iron and chromium spark and a helium tube were also employed at times. The principal piece of work during the year was the measurement of the radial velocities of stars having spectra of the *Orion* type. These spectra are not adapted to very accurate measurement, as the lines are comparatively few and are generally hazy and ill-defined. In spite of this fact, the results have proved fairly accordant. The lines commonly present and measured were those due to one or more of the following elements: helium, oxygen, silicon, nitrogen, hydrogen, magnesium. In a paper to appear shortly

in the *Publications of the Yerkes Observatory,* the detailed results of the investigation of the radial velocities of twenty stars will appear. The velocities found for these stars, expressed in kilometers per second, are given below:—

γ *Pegasi*	+ 5.4	ε *Can. maj.*	+ 27.2
ζ *Cassiopeiæ*	+ 2.9	η *Leonis*	+ 3.5
ε *Cassiopeiæ*	— 5.9	γ *Corvi*	— 7.0
ζ *Persei*	+ 22.1	τ *Herculis*	— 12.7
β *Orionis*	+ 20.7	ζ *Draconis*	— 14.4
γ *Orionis*	+ 18.0	ι *Herculis*	— 16 4
ε *Orionis*	+ 26.7	67 *Ophiuchi*	— 3.1
ζ *Orionis*	+ 18.3	102 *Herculis*	— 10.8
κ *Orionis*	+ 17.1	η *Lyræ*	— 9.1
β *Can. maj.*	+ 32.6	ε *Delphini*	— 26.2

Many of these stars are near the apex or anti-apex of the Sun's way, and if corrected for the solar motion the resulting absolute radial velocities would be small. In the course of the year six spectroscopic binaries were discovered, and have been made the subject of special investigations. An orbit for one of these binaries, η *Orionis,* has been computed by Mr. ADAMS.

Through Professor FROST'S initiative an important co-operative movement, participated in by the principal observatories engaged in investigations of radial velocity, has been set on foot. This involves the systematic measurement of the radial velocities of certain standard stars, selected with particular reference to their suitability for measurement. The results of this work will give for the first time a reliable means of determining systematic errors in investigations of radial velocity.

The Spectra of Stars of Secchi's Fourth Type (Professor HALE, Mr. ELLERMAN, and Mr. PARKHURST).—An investigation of the spectra of red stars of SECCHI'S fourth type was completed during the year. Some 250 photographs, made with a three-prism spectrograph attached to the forty-inch refractor and the two-foot reflector, ranging in exposure time from a few minutes up to twenty-five hours, were obtained in the course of this research. A special study has been made of eight stars, in whose spectra the wave-lengths of several hundred bright and dark lines have been measured. The bright lines have not been certainly identified, but the dark lines have been found to be due to iron, titanium, and various other substances. They have also served for the determination of the radial velo-

cities of the stars. Low-temperature lines, particularly those of calcium, are very conspicuous in these spectra. In many cases the more conspicuous dark lines seem to correspond with lines which are widened in the spectra of sun-spots, but this cannot be made the basis of any theoretical conclusions before further investigations with higher dispersion have been made.

Solar Observations (Professor HALE, Mr. ELLERMAN, and Mr. BARRETT).—The programme of solar work prepared for the Yerkes Observatory includes systematic investigations along the following lines:—

1. Direct Photography: Daily photographs of the Sun on a scale of seven inches to the solar diameter; large-scale photographs of spots and other regions.

2. Monochromatic Photography: Daily photographs with the spectroheliograph, for systematic study of the form, area, distribution, and motion of the calcium vapor on the disk and in the chromosphere and prominences. Comparative photographs in various bright and dark lines and other special researches.

3. Daily photographs of the spectrum: (*a*) of sun-spots, for the systematic study of the positions and intensities of the widened lines and the bright H and K lines; (*b*) of various regions of the photosphere, for the study of the bright H and K lines and the detection of possible changes in the position or intensity of dark lines; (*c*) a special series of photographs taken at the shortest practicable time intervals, near the sun-spot maximum, in order to register, if possible, such remarkable changes in the reversing layer as were recorded on a single plate taken at Kenwood in 1894.

4. Special researches, radiometric, visual, and photographic, on the spectrum of the reversing layer and the chromosphere with a large solar image and powerful grating spectroscope.

5. Investigations on the solar rotation, determined with the spectroheliograph and by spectrographic observations of the photosphere, spots, chromosphere, and prominences.

6. Radiometric investigations of various kinds.

7. Visual observations to supplement those made photographically.

Through unavoidable delays in the construction of the necessary instruments, some of these investigations are not yet

in progress. At present the direct photographs of the Sun are being taken daily with the twelve-inch refractor, which gives a solar image two inches in diameter. In a short time, however, this work will be transferred to the forty-inch telescope, which gives a seven-inch image. The large spectroheliograph constructed for the forty-inch telescope, in spite of its great size and weight, and the special mechanical arrangements required for its operation, has yielded excellent results after a large amount of experimental work. The slits of this instrument are eight inches long, permitting the seven-inch solar image given by the forty-inch telescope to be photographed in monochromatic light. When the construction of the cœlostat reflector had been decided upon, it was thought best to transfer the spectroheliograph from the forty-inch telescope to this instrument. But the delay occasioned by the injury of the latter instrument by fire has caused us to resume the work with the large telescope, and a daily series of photographs is now being secured with the large spectroheliograph. Excellent photographs have been obtained with the remodeled Kenwood grating spectrograph of the widened lines in the spectra of sun-spots, and many of these have been measured. Various special studies have also been made of the spectrum of the chromosphere. The large size of the solar image given by the forty-inch telescope renders it particularly suitable for this work.

Photography of the Moon, Nebulæ, and Star Clusters (Mr. RITCHEY).—Mr. RITCHEY'S successful adaptation of the forty-inch visual refractor for photography by the use of a color-screen and double-slide plate-holder has made it possible for him to obtain many important photographs of the Moon, nebulæ, and star-clusters with the large telescope. When compared with similar photographs taken with the largest photographic refractors, these results appear to surpass in sharpness any previously obtained. The simplicity and cheapness of the color-screen method, and the ease with which it can be applied to existing visual telescopes, will recommend it to those who are not provided with photographic telescopes. In the lack of a measuring-machine, which will be supplied in the immediate future, it has not been possible to make a careful study of the distortion of the negatives produced by the color-screen. There seems to be no doubt, however, that this is of such a character that it can easily be allowed for.

The excellent results obtained by Mr. RITCHEY in photographing the nebula surrounding *Nova Persei,* as well as various other nebulæ and star-clusters, with the two-foot reflector recently constructed in the observatory shops, have demonstrated that work of great importance can be done with a properly constructed reflecting telescope of comparatively small aperture. There can be no doubt that the development of reflecting telescopes during the last fifty years has been greatly retarded by the insufficient attention given to the mechanical design and construction of the mountings. The excellent photographs obtained with the Crossley reflector by Professor KEELER and Mr. PERRINE indicate that with sufficient skill and persistence some of the older instruments may yield good results, but with suitably designed mountings most of the difficulties experienced in this work disappear. The remarkable photographic efficiency of the reflector is shown by the fact that stars at the limit of vision with the forty-inch refractor can be photographed with the two-foot reflector in forty minutes. With longer exposures innumerable stars, one or perhaps two magnitudes fainter than those at the limit of the forty-inch, can be photographed. As there can be no doubt that larger reflectors, when used under good atmospheric conditions, will produce proportionately better results, it is hoped that means may soon be found to mount the five-foot mirror made by Mr. RITCHEY in the optical shop of the Yerkes Observatory.

Photometry (Mr. PARKHURST).—For some time past the Yerkes Observatory has been co-operating with the Harvard, McCormick, and Lick observatories in the work of determining standards for faint stellar magnitudes with a wedge photometer supplied by the Rumford Committee of the American Academy of Arts and Sciences. Mr. PARKHURST has made a careful series of determinations of the wedge constant by the method of standard stars and also with a wheel photometer. The wedge photometer has been systematically used with a six-inch reflector and with the twelve-inch and forty-inch refractors. In addition to the observations of faint standards made with the forty-inch telescope, which have been fewer than was hoped on account of the unusually bad weather and the small amount of time that could be spared from other investigations, Mr.

PARKHURST has photographed many of the fields containing the standards with the two-foot reflector. Paper prints of these show stars down to the seventeenth magnitude or fainter, and render the identification of the faint standards certain, a work equally important with the photometric measures themselves. In addition to this photometric work, Mr. PARKHURST has continued his observations of variable stars, giving special attention to those which are exceedingly faint at minimum.

Spectroscopic Laboratory (Professor HALE and Dr. KENT). —During the year the equipment of the spectroscopic laboratory has been greatly increased, and now includes a six-inch concave grating spectroscope of 21½ feet focal length, with smaller concave gratings for special purposes; a 3 K. W. 110-volt alternating dynamo, presented by Dr. GEORGE S. ISHAM; a 1 K. W. transformer, giving 15,000 or 30,000 volts; various induction coils, including a high-frequency coil presented by Mr. JAMES LYMAN; a large condenser, volt-, watt-, and ammeters, and other apparatus presented by Dr. ISHAM; and various miscellaneous instruments. The various light sources, including the arc in air, rotating arc in liquids, spark in air at various pressures, spark in liquids, etc., are arranged on the circumference of a circular table, at the center of which is a plane mirror. By means of this mirror the light from any source can be reflected to a large concave mirror, which forms an image of the source on the slit of the concave grating spectroscope in the adjoining room. To pass from one source to another it is only necessary to rotate the plane mirror. This arrangement has proved very convenient in practice, and is believed to eliminate the danger of such displacements of lines as sometimes occur when an adjustable image lens is used in front of the slit.

The principal work of the spectroscopic laboratory during the year has been an investigation on the spark spectra of iron and other metals in liquids and in air at high pressures, in connection with solar and stellar spectra. By changing the constants of the discharge circuit, or by varying the pressure of the air in which the spark is observed, it has been found possible to pass by successive steps from a bright line spectrum to one consisting almost wholly of dark lines in the ultra-violet. The reversals appear first in the ultra-violet and gradually advance

toward the less refrangible region, thus reproducing the effect observed by Professor CAMPBELL in certain stars, whose spectra contain dark hydrogen lines in the ultra-violet and bright ones in the less refrangible region. A careful study has been made of the displacements of the lines which accompany the changes of the absorption phenomena, and these are being discussed with reference to their bearing on the spectra of temporary stars.

Cœlostat Reflecting Telescope.—In view of the excellent photographs of the corona obtained by Professor BARNARD and Mr. RITCHEY at the eclipse of May 28, 1900, with the aid of a cœlostat constructed in the observatory shops, it was decided to build a much larger cœlostat, to be used with concave mirrors of various apertures and focal lengths for astronomical photography and for spectroscopic observations requiring the use of large-grating spectroscopes mounted under laboratory conditions. The cœlostat, which had a mirror of thirty inches aperture, was completed with the aid of grants from the Rumford and Draper Funds in the autumn of 1902. Light from the cœlostat mirror was reflected to a second plane mirror of twenty-four inches aperture, which sent the rays in a southwesterly direction to a concave mirror of sixty-two feet focal length. This mirror returned the rays and formed the image near the cœlostat. All parts of the apparatus, including the mirrors, were made in the observatory shops under the direction of Mr. RITCHEY. For direct photography a double-slide plate-holder was to be used. For photographic work on the spectra of some of the brightest stars there was provided a concave-grating spectrograph, having a six-inch grating ruled by Mr. JEWELL on Professor ROWLAND'S engine for this research, used in conjunction with a collimating lens of five inches aperture and thirteen feet focal length. This was mounted on solid piers in a double-walled room, arranged with automatic apparatus to maintain a constant temperature. When in process of adjustment, the insulation of the wires connected with the comparison-spark apparatus broke down, setting fire to the walls of the room. A high wind was blowing, and it was impossible to extinguish the flames, which destroyed the spectrograph house and the building containing the cœlostat and mirrors. The twenty-four-inch plane mirror was saved, and

most of the heavier parts of the apparatus were not injured. The reconstruction of the instruments is going on rapidly in the Observatory shops, and it is hoped that they may be in use during the summer of 1903.

Bruce Photographic Telescope.—A ten-inch photographic objective of the portrait-lens type, having a focal length of fifty inches, was completed by BRASHEAR and thoroughly tested by Professor BARNARD during the year. There has been great delay in securing a suitable objective, on account of the difficulty of obtaining a sufficiently large field. With the present lens, used with a plane plate, it is expected that good definition will be obtained over a field about 9° in diameter. This will be extended to 12° by the use of a curved plate. WARNER & SWASEY have made designs for the mounting, and it is hoped that the instrument will be ready for use in the summer of 1903.

Publications.—Volume II of the *Publications of the Yerkes Observatory*, containing papers by Messrs. BURNHAM, BARNARD, MOULTON, FROST, and ADAMS; HALE, ELLERMAN, and PARKHURST; RITCHEY; and LAVES, will be published within a few months. Observatory bulletins are now issued rarely, and are used only to provide for the publication of information which does not naturally find a place in other channels. The usual number of scientific papers have been communicated by members of the staff to the various journals.

Grant from the Carnegie Institution.—The Carnegie Institution has appropriated $4,000 to be expended by the Director of the Yerkes Observatory for various investigations to be undertaken during the year 1903. These will include:—

1. A photographic investigation of stellar parallaxes, to be made by Dr. FRANK SCHLESINGER, now in charge of the International Latitude Observatory at Ukiah, California. Dr. SCHLESINGER will commence his work at the Yerkes Observatory in May.

2. Special photometric observations, by Mr. J. A. PARKHURST. Hitherto Mr. PARKHURST has devoted the greater part of his time to the measurement and reduction of stellar spectra, but hereafter his entire attention will be given to photometric work and related investigations on variable stars.

3. A detailed study of the photographs of the Sun, number-

ing over 3,000, taken during the years 1891-1896 with the spectroheliograph of the Kenwood Observatory. Mr. PHILIP FOX, formerly Instructor in Physics at Dartmouth College, is assisting in this work.

4. Various special investigations, which will probably include stellar and solar spectroscopic work with the cœlostat reflector.

GEORGE E. HALE, *Director*.

LICK OBSERVATORY, MOUNT HAMILTON, CALIFORNIA.*

The Lick Observatory suffered an irreparable loss in the untimely death on August 12, 1900, of Dr. JAMES EDWARD KEELER, Director from June 1, 1898. The announcement of his death came as a great shock to his colleagues and friends widespread, who had seen before him a career of rarest promise. The elements of his successes were simple, and plainly in view. His openness and honesty of character, his willingness and quickness to see all points of view, his strong appreciation of the humorous as well as the serious, and, above all, his abounding good sense,—these traits made his companionship delightful and charming. His published papers have a completeness, a ripeness, and a finish rarely seen.

Our appreciation of his worth has not grown dim with time.

Dr. KEELER'S last observations were made with the Crossley reflector in the hope of recording the image of a ninth satellite of *Saturn*, reported to exist by Professor W. H. PICKERING. No trace of the satellite was detected, but the plate of June 28, 1900, led to the discovery of an asteroid, *1900 GA*,—probably the faintest one known.

While the Observatory is pre-eminently an observation-station, yet it is not so in a narrow sense. Success in observational work demands, (1) knowledge of what has been done by others; (2) knowledge of pending problems, and of the most promising methods for their solution; (3) knowledge as to how observations will be used, and when they should be made, in order that they may bear most efficiently upon the problem.

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*Slightly abridged by Professor CAMPBELL from his "Biennial Report to the President of the University of California," covering the period July 1, 1900, to July 1, 1902.

An institution whose efforts were confined strictly to securing observations would soon be making inferior observations. Progressive observers must be acquainted with the theories of their subjects, and must undertake occasional theoretical studies, as well as computations of considerable extent. The Director has constantly held in mind the necessity for increasing the efficiency of the Observatory wherever possible. The instruments have been kept in perfect repair, and efforts have been made to provide all desirable improvements. Lack of financial resources has necessarily limited the latter work to the most pressing cases.

The hydraulic engine for turning the dome of the great telescope had been working badly for several years, limiting to an appreciable extent the productiveness of the telescope itself. The expert machinist who had superintended the erection of the dome was employed in January, 1901, to examine its running mechanism, and to make the necessary improvements. It was found that the brass feed-cylinders of the engine were badly worn, permitting very considerable leakage, thereby in effect decreasing the hydraulic pressure on the pistons. The cylinders were drilled true, and new piston-heads were provided. It is gratifying to report that the dome and its entire mechanism now perform at least as satisfactorily as they did when new.

The original design of the great telescope did not provide for power to wind the driving-clock; it was wound by hand. A Pelton water-wheel was installed for this purpose in 1890, but it never had sufficient power to do the work without assistance from the observer. In the past year the water-power has been applied more directly to the wheel, and the crude device for communicating the power to the clock has been replaced by sprocket wheels and chain. The winding apparatus now acts immediately, without assistance from the observer.

Further to increase its efficiency, Mr. WRIGHT has designed, and the instrument-maker has constructed, a device for turning the water-power on and off automatically. This will be put in place in the near future; and it is hoped that the observer's duties in connection with the clock will be confined to starting it in the evening and stopping it in the morning.

The need of a wind-screen in the opening of the dome had been felt for many years. The violent vibration of the telescope when the opening was turned toward the wind made it impossible to secure accurate observations. A temporary screen was put in place in the fall of 1900, especially for use in the *Eros* campaign. This served its purpose so well that a permanent screen on analogous lines was designed in 1901 by our carpenter, and was manufactured and put in place by him.

It is necessary that frequent repairs be made to the great telescope. This is not at all surprising in view of the fact that this excellent instrument is used throughout every good night. A serious defect recently developed in the Right Ascension slow-motion and clamping trains. This gradually grew more troublesome, until in April, 1902, these trains suddenly refused to operate. Upon investigation it was found that the trouble existed at the junction of the polar and declination axes. Unfortunately, the construction was such that the critical point was not accessible. Repairs called either for the dismounting of the telescope-tube, the declination-axis, and many minor pieces, or for the cutting of a hole through the cast-iron sleeve of the declination-axis. The latter method seemed preferable. My plans for this purpose were submitted to the makers of the telescope, the WARNER & SWASEY COMPANY, and met with their approval. When the hole was cut, it was found that the important cast-iron bearing block, where the trains turn through a right angle, had broken. This block was replaced by a larger steel one, constructed in our shops. For the first time in its history, I believe, the telescope was disabled for observational work. This was for two days only, while the new block was making. The value of our instrument-making shop was well illustrated on this occasion. Had it been necessary to secure machinists and tools from a distance to cut the hole in the telescope, and to have the broken parts constructed elsewhere, a delay of several weeks must have ensued, and the expense would have been correspondingly great.

The efficiency of the 36-inch equatorial was enormously increased a few years ago by illuminating the setting-circles by means of electric lights operated from the eye-end, according to Messrs. CAMPBELL and WRIGHT'S plans, thereby making it unnecessary for the observer to climb the high mounting, as he

had theretofore done many times per night. Astronomer HUSSEY has recently equipped the twelve-inch equatorial (under his charge) in a similar manner, with good results.

Many minor improvements on the mounting of the Crossley reflector have contributed somewhat to its stability, but the necessity for providing this instrument with a new mounting has become more apparent with time to all who have used it. Director KEELER's remarkable success was achieved at enormous expense of time and physical energy. On the average, it was necessary for him to make four or five exposures on an object before a suitable negative was secured; and in many cases he had to be satisfied with enlarged and elongated star images. His experiences have been those of Assistant Astronomer PERRINE, who is now in charge of the instrument. If the mirror were provided with a suitable mounting, observers possessing their great skill should have no difficulty in obtaining three successful negatives out of four attempts. The subject has been brought to the attention of the Lick Observatory Committee of the Regents, who have authorized the construction of a new mounting. Working drawings have been made by the firm of HARRON, RICKARD & MCCONE in accordance with general designs supplied by Mr. PERRINE. Bids have been received from three responsible firms, and the contract is ready for letting. The smaller and more delicate parts of the mounting have been designed by Mr. PERRINE, and these will be constructed in our instrument-making shops. It is hoped that the change from old to new may be made before the end of the year.

The original driving-clock of the Crossley reflector was replaced several years ago by a vastly more powerful one, from designs by Mr. HUSSEY. With the installation of the new mounting, only the 36¼-inch mirror of the original telescope will remain in use.

A generation ago the astronomer ordered his telescope and expected it to meet all his requirements. This is no longer sufficient. The wonderful developments of our science call for special instruments to do special work, and the so-called universal instrument is out of date. This is especially true in investigations along astrophysical lines. The successful instrument must have maximum efficiency in the problem to be

solved. Every observatory of our class requires an instrument-making shop near at hand. This requirement is especially pressing here, on account of our unusual isolation.

The shops at the Lick Observatory were entirely inadequate for their purpose. The equipment consisted of two small, antiquated foot-power lathes, an antiquated hand-drill, files, etc.; and the carpenter's hand tools. The quantity of construction possible by their means was small, many vital parts of the instruments could not be made at all, vexatious delays in construction elsewhere were frequent, and our plans were rapidly falling in arrears to such an extent that the efficiency of the Observatory suffered severely. I therefore decided to utilize any available budget funds for the improvement of the machine-shops.

The carpenter-shop, paint-shop, and forge occupied adjoining rooms in a small brick building near the great dome, constructed by the Lick Trust. The paint-shop was removed to an isolated building beyond the barn, both to diminish risks from fire and to increase the space in the carpenter-shop. The inside walls of the forge-room were likewise removed. The resulting shop is twenty feet by twenty-six feet. An addition to this shop was built by the Observatory workmen in 1891, inside dimensions twenty-five by thirty-three feet, from brick left in the original Lick Trust kilns. This room had been used for storage, for the metal-working shop, and for a steam boiler and engine employed in charging storage batteries and in cutting the Observatory wood. The engine and wood-saw were removed to a small brick building, outside dimensions eleven by fourteen feet, built in 1901 to the east of the barn; and storage space has been found elsewhere. The rearranged room admirably meets the requirements of a complete instrument-making shop, on the desired scale. A Foos four-horse-power gasoline-engine was installed in the shop in place of the steam-engine. It drives all the metal- and wood-working machines described below. It is always ready to start, without waiting for steam to rise; the expense of fuel is small; it does not need the attention of a fireman; and it does not heat the work-room unduly. A Brown & Sharpe No. 1 Universal milling machine, a Brown & Sharpe tool-grinding machine, a modern wood-turning lathe, a wood rip-saw and an emery grinder were pur-

chased in 1901. The old foot-lathes were modified to adapt them to power. The necessary shafting, pulleys, belting, attachments and small tools were likewise provided. The gasoline-engine drives the dynamo also.

The thoughtful generosity of Mrs. HEARST has enabled me to arrange for the completion of the shops without the delay that I feared might occur, by purchasing a modern lathe of fourteen-inch swing and eight-foot bed, with all necessary attachments; a power drill; a power saw for cutting metal; a cross-cut saw for wood; a wood-shaper; a small tempering and reducing furnace; and minor tools.

The schoolhouse, though small, is very complete and comfortable. The school is attended by nine children of various members of the staff. The teacher is supplied by Santa Clara County.

A tract of forty acres of land adjoining the reservation on the east, formerly belonging to JACOB WANDELL, was purchased by the University in 1901. Its location made control by the Observatory extremely desirable.

The principal buildings have for many years been painted a dull red color. This color was not in keeping with the character of the institution, nor was the quality of the paint adapted to the requirements of our climate. The smaller buildings and the residences were painted in various colors, and the effect was not at all pleasing. It was decided to have the outsides of all the buildings on the mountain painted on a uniform system, the roof to be tile-red, and the walls to be light yellow sandstone color, all to match the colors of the old California Mission buildings. The change was made last year for many of the smaller buildings, and the main building is now undergoing transformation. The general effect promises to be all that could be desired.

With the advice and assistance of the President, to meet a pressing want, the Lick Observatory early in 1901 began to publish the results of its observations in the Lick Observatory Bulletin. The earlier papers by members of the staff had appeared in various astronomical journals. While this plan relieved the University of expense and considerable labor, yet the vexatious delays sometimes occurring in the issue of important papers, and the appearance of the papers in so many

mediums, were serious objections. The new plan has worked well, and the Bulletins are in great demand. They have been supplied gratis to other observatories, to academies of sciences, and to the principal investigators. Twenty-seven numbers have been issued up to date, and the distribution list includes about 430 addresses. The funds available for last year did not permit the insertion of many illustrations. The increased appropriation for the year 1902 will provide for a greater number.

The Observatory library is growing rapidly, so far as growth by exchange of publications is concerned, but there have been almost no funds available for purchases. Early volumes of several scientific periodicals, early volumes of observatory reports now obtainable only from second-hand dealers, and many standard books, both old and recent, are greatly needed. It is planned to supply a few of the most pressing of these needs in the near future from the funds provided by Mrs. HEARST. The library contains about 5,000 volumes and 4,800 pamphlets. It has outgrown the capacity of the library-room. Suitable hardwood book-cases have been constructed in the main corridor for the overflow. In this way the space requirements will probably be met for many years. The library is in charge of Assistant Astronomer AITKEN.

Up to the beginning of the year 1901 it had been the practice of the directors of the Observatory to write all the letters personally. The correspondence has always been heavy, and the tax upon valuable time and physical strength for this purely mechanical labor has been very great. It seemed to me that modern methods should be adopted. The former Secretary's time had through experience become too valuable scientifically to justify his retention in that office. It was arranged that his services should be available entirely for investigational work, and a secretary who was also a stenographer was employed in his stead.

The arrangements inaugurated by Director KEELER regarding fellowships in the Lick Observatory have been very satisfactory. The immediate output of scientific results would be considerably greater if the funds, originally paid to an astronomer and now paid to the Fellows, could be used in the employment of regular assistants who would spend all their time

on the mountain. But the training of the astronomers of the future is so manifestly one of the duties of the University that the arrangement should be continued.

The greater part of the time of the Fellows during their first two years of residence is devoted to assisting the astronomers in the more routine parts of their work; but with the acquirement of experience and skill, greater responsibilities are placed upon them, and the assignment of original investigations to them is planned in all cases.

It is a great pleasure to record the following generous gifts to the Lick Observatory:—

In December, 1900, D. O. MILLS, Esq., provided a fund of $24,000, plus ten per cent. for unexpected expenses, for a spectroscopic expedition to the southern hemisphere. This gift is noted more fully below.

WILLIAM H. CROCKER, Esq., provided a fund of $3,000 to defray the expenses of an expedition to Sumatra to observe the total solar eclipse of May 18, 1901. The work of the expedition is described in detail in other paragraphs.

A grant of $500 from the Draper Fund of the National Academy of Sciences was made in February, 1901, for the purpose of constructing a modern one-prism spectrograph. The designing of this instrument was delayed until the completion of the reflecting telescope for the southern hemisphere.

Mr. D. O. MILLS has presented the sum of $1,000 for the reconstruction of the original Mills spectrograph. It was built in the age of brass; the new instrument will be of steel in all its vital parts. It will also contain many important modifications resulting from our six years' experience with the original instrument. The reconstruction is now under way.

Mrs. PHŒBE A. HEARST has thoughtfully provided the sum of $2,500, available during the year 1902, to be expended for equipment purposes. As a result of her generous gift, several departments of the Observatory will be equipped for more efficient work.

The total value of these gifts in the past year and a half is $33,400.

The Wells, Fargo Express Company, on several occasions, granted half-rates on heavy and valuable shipments. In recognition of our time signals, the Southern Pacific Company

has given reduced rates for passage and freight in connection with eclipse expeditions, shipment of heavy goods, etc. The Toyo Kisen Kaisha, the Occidental and Oriental Steamship Company, the Pacific Mail Steamship Company, and the Dutch East India steamship companies granted concessions to the Sumatra Eclipse observers. Prominent firms in San Francisco and in the East have in every case supplied tools for our instrument-shops at rates lower than commercial firms must pay. The total value of the concessions cited above approximates $1,800 for the past two years. The power of our resources to produce useful results was increased to that extent, and the thanks of the Observatory are due to the companies mentioned.

It was Director KEELER's purpose to secure with the Crossley Reflector satisfactory photographs of about one hundred of the principal nebulæ and star-clusters. The portions of his programme available for observation in our clear summer weather were practically complete at the time of his death, but those in position during the cloudy winter months were incomplete. We have made it a duty to carry on Director KEELER's work as rapidly as possible, but the necessity for securing observations of the planet *Eros* and of the eclipse in Sumatra has interfered to some extent. The amount of clear weather in the past winter and spring has likewise been very much less than the average, and gaps in this part of his programme still remain. As soon as satisfactory negatives of all the objects have been obtained, the results should be published in the best possible manner. The making of plates for reproducing the photographs will be a very painstaking and expensive process, but it is hoped that funds may be obtained from private sources to an amount sufficient to do justice to Dr. KEELER's work and memory.

Through the continued generosity of Mr. WILLIAM H. CROCKER, a well-equipped expedition, in charge of Acting Astronomer PERRINE, accompanied by Assistant RALPH H. CURTISS, sailed from San Francisco in February, 1901, to observe the total solar eclipse of May 18th, on the west coast of Sumatra. The affairs of the expedition, personal, financial, and scientific, were admirably managed by Mr. PERRINE. The ten instruments were duly mounted and placed in perfect adjustment. Fifteen volunteer assistants, Dutch residents in Sumatra,

were trained to their duties, and the entire programme of photographic exposures outlined for the expedition went through without a hitch. All went well, save that the eclipsed Sun was obscured at the beginning of totality by thin clouds, which gradually thickened during the 6½ minutes of the eclipse.

To the surprise of the observers, when the negatives were developed it was found that the observations were extremely satisfactory, valuable results having been secured with all of the ten instruments. The instruments and photographs were delayed in transit homeward, and did not reach Mt. Hamilton until October. Examination of the plates more than confirmed Mr. PERRINE'S report. A study of the photographs has shown that, in spite of the thin clouds, the expedition was at least as successful as any eclipse expedition ever sent out by any institution.

The general results have been published in a preliminary manner in Lick Observatory Bulletin No. 9, but attention should be called to a few of the more important ones:—

The photographs obtained with the forty-foot camera are admirable, the general features of the inner and middle corona being shown as well as if there had been no clouds. A most interesting and unique coronal disturbance was recorded in position-angle 60°. A comparison of the solar photographs with those made on the days preceding and following the date of the eclipse by English observers in India led to the very important conclusion that the coronal disturbance was situated immediately above the prominent and only sun-spot group visible on those days.

The spectrographic and polarographic results were completely successful, perhaps more so than would have resulted from an unobscured eclipse. They established that the spectrum of the outer corona is identical with that of ordinary sunlight, and therefore that the light of the outer corona is not inherent, but is reflected light originating in the main body of the Sun; that the spectrum of the inner corona is continuous, and therefore is not reflected sunlight, but is inherent; that the outer corona shows the strong polarization effects that would be expected to result from its character as reflected light; and that the inner corona gives only slight

evidence of polarization, as would be expected from light largely of an inherent character.

Mr. PERRINE has carefully examined the plates secured with four cameras for the purpose of detecting any possible intra-Mercurial planets. The instruments gave splendid definition, and in the unobscured areas surrounding the Sun stars down to the ninth magnitude were recorded. The search was highly satisfactory for more than two thirds of the area under examination, but the clouds prevented complete success in the remaining one third. No unexpected objects were detected. While the discovery of unknown objects as a result of this search would have been more interesting, yet negative and positive results would possess equal value scientifically.

The expedition received very extensive help from the Dutch Government in Sumatra, from the lines of steamers patronized, and from individuals at all transfer points.

Mr. CROCKER'S services to eclipse astronomy have been highly appreciated by astronomers and other men of science throughout the world.

The discovery of the minor planet *Eros* in 1898, and the recognition of the unusual opportunities offered by it for an improvement in our knowledge of the distance of the Sun, led to the organization of a coöperative scheme on the part of forty or fifty leading observatories, to secure the necessary observations in the fall of 1900. The Lick Observatory entered energetically upon the programme outlined. Astronomer TUCKER secured more than two thousand meridian-circle observations of the 678 reference stars, required as a basis for the entire problem. The microscopes were read by Dr. R. T. CRAWFORD for about 1,600 of the observations, and he rendered some assistance in the computations, but Mr. TUCKER was unassisted in the bulk of the reductions. The results were published in Bulletins Nos. 1 and 2, in February and May, 1901, respectively. The prompt completion and publication of this extensive piece of work, long in advance of the appearance of results from the other observatories, called forth many expressions of surprise and admiration for the energy and skill of the astronomer in charge.

Careful micrometer measures of the position of *Eros* were obtained by Astronomer HUSSEY and Assistant Astronomer

AITKEN, with the thirty-six-inch equatorial. The former made 832 measures in Right Ascension, and 896 in Declination; the latter 1,650 in Right Ascension and 729 in Declination. Photographic observations were secured in great numbers with the Crossley reflector by Assistant Astronomer PERRINE, assisted by Fellow H. K. PALMER. They include 344 plates on sixty-three nights for accurate meridian places of the planet; 511 plates on thirty-seven nights for a parallax; 110 charting and connecting plates; total, 965 plates, of which 854 contain short exposures for measurement, carrying over four thousand images of the asteroid. The micrometer results, and a list of the photographic plates, are published in Bulletin No. 13. The measurement and reduction of these plates will be an enormous task. Fortunately, Professor REES, Director of Columbia College Observatory, has agreed to undertake that work. His efficient bureau of measurement and reduction, in immediate charge of Professor JACOBY, has already measured and reduced a number of the plates.

Perhaps the most interesting astronomical events of recent years relate to the new star in *Perseus*, discovered in Edinburgh on February 22, 1901. The Lick Observatory, in common with all similar institutions, made immediate plans to bring every available resource to bear upon the study of this star. Its position was measured by Mr. TUCKER with the meridian-circle, and by Mr. AITKEN with the thirty-six-inch equatorial on several occasions in the spring and summer of 1901. It is clear from their observations, amply confirmed by those made elsewhere, that the new star is at least as far away as the faint stars surrounding it, and that its motion with reference to the surrounding stars is so slight as to elude detection for the present. Our two spectroscopes suitable for the study of the new star were sent to Sumatra with the Eclipse Expedition only two or three days before the announcement of the discovery reached us. Fortunately, the Observatory possessed a good collection of lenses and prisms; and from these, spectroscopes were mounted very promptly in our instrument-making shops, so that practically no time was lost on that account. The spectroscopic observations by Messrs. CAMPBELL and WRIGHT, assisted by Dr. REESE, were extremely fruitful in results. They have been published in Bulletin No. 8.

Spectrum photographs were secured by Fellow JOEL STEBBINS with the Crossley reflector, which led to the discovery of two new bright lines in the ultra-violet portion of the spectrum. The brightness of the star was observed on all possible occasions, during its period of rapid fluctuation, by Messrs. AITKEN and STEBBINS. It was the brightest star in the northern sky on February 24th; it has now declined to the ninth magnitude, having been in the mean time converted into a nebula.

A photograph by WOLF, of Heidelberg, on August 23, 1901, had led to the discovery of masses of nebulosity in the vicinity of the new star. A photograph by RITCHEY, of the Yerkes Observatory, on September 20th, confirmed and extended the discovery, showing that the new star was apparently situated in a nebulous mass nearly circular in form, and of great extent. The photograph of this region made by Mr. PERRINE with the Crossley reflector, on November 7th and 8th, led to the extraordinary discovery that the well-defined nuclei in the nebula were apparently in rapid motion; the magnitude of the apparent motion being at least seventy-five times as great as any sidereal motion previously known. Telegraphic announcement of this discovery was made at once, and intense interest was taken in the subject. A photograph made by RITCHEY at the Yerkes Observatory, on November 9th, afforded full and independent confirmation of Mr. PERRINE's remarkable discovery. Photographs made at intervals throughout the winter have enabled us to follow the motions of the brighter masses.

Following this discovery, there were frequent expressions of regret that no record of the nebulosity had been obtained between the discovery of the star in February and the epoch of WOLF's photograph. Numerous short-exposure plates of the new star had been obtained by Messrs. PALMER and DALL with the Crossley reflector early in the year. Examination of these by Mr. PERRINE in January, 1902, led to the happy discovery that two rings of nebulosity surrounding the new star were beautifully recorded on Mr. PALMER's plate of March 29th. We were thus able to extend the history of the phenomenon backward five months.

The nature of the phenomenon is a mooted question. The favorite theory is that invisible masses of nebulosity existed

in this region previous to the formation of the new star; and that the great wave of light, sent out when the brightness of the star was at a maximum, was sufficient to illuminate the dark masses and make them visible to us by reflected light. Bearing upon this question, Mr. PERRINE secured valuable polariscopic evidence. A photograph of the nebula was obtained after passing the light through a double-image prism, placed at a short distance in front of the plate-holder in the Crossley reflector. Two images of each of the principal nuclei were recorded in such a way as to make it certain that the polarization effects to be expected from reflected light are entirely absent. It is hoped that a complete series of observations of this interesting object may be obtained during the coming autumn, and that the principal masses will be bright enough to permit a study of their spectra by means of a small spectrograph that Mr. PERRINE has planned.

The consensus of opinion is that the new star is the result of a violent collision between two dark stars, or between a dark star and a nebula. It can easily be shown that the kinetic energy of two such bodies, approaching and colliding with enormous relative speed, would be converted into heat in sufficient quantities to transform the dark bodies into incandescent gases. The history of previous new stars had led us to expect that the spectrum would gradually change into that of a nebula, and in this we were not disappointed. For a suitable study of the present nebular spectrum of the new star it was necessary that further and more accurate investigations be made upon the spectra of the well-known nebulæ. These investigations were undertaken with great success by Assistant Astronomer WRIGHT. His results have been published in Bulletin No. 19. Not only did he determine the positions of many well-known nebular lines more accurately than had previously been done, but a number of very interesting new lines were detected.

Very little attention has been given to the subject of comet-seeking, on account of pressure of work in other lines, although search has been made by Mr. PERRINE for a few periodic comets whose returns were expected. These include the Di Vico-Swift comet, BARNARD'S comet of 1884, and SWIFT'S comet of 1895. No trace of these was discovered, no doubt on account of their faintness, or of their defective orbits.

Micrometer observations of comets in the past two years have been secured, as follows:—

Comet *a* 1900,	AITKEN, 3 nights,	PERRINE, 4 nights.
" *b* 1900,	" 10 "	" 3 "
" *c* 1900,	" 6 "	
" *a* 1901,	" 2 "	
" *a* 1902,	" 2 "	

The measures of Comet *a* 1901 and of Comet *a* 1902 were the only ones made in the United States. Valuable photographs of Comet *a* 1901 were secured by Mr. PERRINE at the Eclipse Station in Sumatra. An orbit of Comet *b* 1900 was computed by Mr. PERRINE, and of Comet *c* 1900 by Mr. AITKEN. Some very interesting photographs of Comet *b* 1900 were secured by Mr. PALMER.

Extensive series of measures of satellites of planets were obtained by various members of the staff, observations being limited in all cases to those most desired by investigators of their orbits.

Two hundred and fifteen observations of the relative positions of the satellites of *Saturn* were made by Mr. HUSSEY with the thirty-six-inch equatorial.

Mr. AITKEN made the following observations with the thirty-six-inch equatorial:—

Satellites of *Uranus*,	27 nights.
" " *Neptune*,	13 "
" " *Mars*,	7 "
Fifth satellite of *Jupiter*,	2 "

At the request of Professor NEWCOMB, Mr. PERRINE photographed the planet *Neptune* and its satellite on thirty plates, in January, 1902, with the Crossley reflector. The measurements of these plates furnish fifty-one determinations of the position of the satellite, with reference to its primary. Photographic methods have been but little used in this line of work, and it is interesting to note that the smallness of the errors of observation justifies the application of the method in all possible cases.

The work with the meridian-circle has been most efficiently prosecuted. Since July 1, 1900, Mr. TUCKER has obtained 6,500 complete observations. These include observations of *Eros* comparison-stars; of *Eros* itself; of *Nova Persei;* and of

zodiacal stars, greatly needed at the present time, to be used as a basis for improving the orbits of the major planets.

The manuscript for *Lick Observatory Publications,* Volume VI, is entirely ready for the printer. The volume will contain results of meridian-circle work from July, 1896, to March, 1901, and will include about 14,000 complete observations of 4,500 stars. The labor entailed in securing, reducing, and preparing these observations for publication has been very great. Mr. TUCKER has had assistance from Messrs. CRAWFORD, DALL, CURTISS, and PALMER, amounting to about six months full time of one computer during the past two years. The remainder of the work has been carried on without assistance.

Fellow R. T. CRAWFORD assisted in meridian-circle work during the years 1898-1901. At the end of his service he received the degree of Doctor of Philosophy, having taken for his thesis the subject of "The Refraction-Constant at Mt. Hamilton."

The department of astronomy known as Double Stars has been most ably advanced by Messrs. HUSSEY and AITKEN. The former has devoted perhaps three fourths of his time and the latter one half his time to this line of investigation. Their programmes have been admirably developed and systematized, and results of prime importance have been surprisingly numerous. It is not too much to say that their discoveries and observations of new double stars, and their measures of known double stars, outnumber several-fold the corresponding output of all other observatories in the past two years. An equally satisfactory statement can be ventured as to the accuracy attained. Both observers have devoted a portion of their time to the discovery of new pairs. Mr. HUSSEY has found 312 systems in the past two years, and 564 since 1898. They may be classified as follows:—

Distances between 0".00 and 0".25,	41 pairs.
0 .26 " 0 .50,	103 "
0 .51 " 1 .00,	123 "
1 .01 " 2 .00,	128 "
2 .01 " 5 .00,	168 "
Over 5 .00,	1 "
Total	564 pairs.

It will be seen that 47 per cent of his discoveries have distances less than 1″, and 70 per cent less than 2″.

The corresponding discoveries by Mr. AITKEN have been 249 since July, 1900, and 345 since 1898, as follows:—

Distances between	0″.00	and	0″.25,	20 pairs.
	0 .26	"	0 .50	55 "
	0 .51	"	1 .00,	78 "
	1 .01	"	2 .00,	91 "
	2 .01	"	5 .25,	101 "
			Total	345 pairs.

Forty-five per cent of these are under 1″, and 71 per cent under 2″.

By way of explanation, it should be said that in general the closer the components of a pair the more interesting and important it is. The majority of stars in which orbital motions have been detected are closer than 1″. Up to the present time about 1,500 double stars with distances under 1″ have been discovered at all the observatories. More than one third of these have been found at the Lick Observatory, and more than one fourth of the whole number have been discovered here within the last three years.

Many interesting results have come from the systematic observation of the well-known interesting pairs. Of these, the most striking case is δ *Equulei*. It was supposed that its period of revolution was 11.4 years,—surpassed in rapidity of motion only by κ *Pegasi*, period 11⅓ years. In the fall of 1900 it was noticed by Mr. AITKEN that the components of δ *Equulei* were not following the paths marked out for them by the orbit hitherto accepted as substantially final. Mr. HUSSEY investigated the question of their orbit, making use of all the known observations. He came to the conclusion that the chances were greatly in favor of a period only one-half the length of that previously assumed, namely, 5.7 years. Systematic observations by Messrs. HUSSEY and AITKEN during the past year have established the correctness of this view. The period of this interesting binary is fifty per cent shorter than that of any other known double star. Observations of this system obtained with the Mills spectrograph are in harmony with Mr. HUSSEY's theory.

Mr. HUSSEY has also in the past two years secured

881	micrometrical observations of	newly discovered pairs.
801	" " "	W. Struve pairs.
54	" " "	Otto Struve pairs.
63	" " "	miscellaneous pairs.
Total, 1,899		

Mr. AITKEN has obtained 1,431 observations, his observing-list being mainly composed of known rapid binaries, and other close and difficult pairs. He has likewise computed orbits for 99 *Herculis*, ζ *Sagittarii*, and β *Delphini*.

Mr. HUSSEY completed his observations and discussions of the Otto Struve double stars, and his work was issued in the summer of 1901 as Volume V, *Publications of the Lick Observatory*. This volume is of great utility to double-star observers. It met with an excellent reception from his fellow-workers.

In the year 1900, the Lick Observatory agreed to coöperate with the Harvard College, Yerkes, and University of Virginia observatories, in observing photometrically ten stars in the immediate vicinity of each of thirty-six well-known variable stars, under the auspices of the Rumford Committee of the American Academy of Arts and Sciences. The photometer was designed and supplied by Professor PICKERING, Chairman of the Committee; but, on account of the greater brightness of the images formed by the thirty-six-inch telescope, it was necessary to change its form before beginning observations. The work on *Eros*, the solar eclipse, and the new star, combined with the smallness of our staff, delayed work on the programme until June of this year. Results are now rapidly being obtained by Mr. AITKEN and Dr. S. D. TOWNLEY, of the Berkeley Astronomical Department, who spent his summer vacation here in several phases of photometric work.

The Crossley reflector has been busy on practically every good night. In addition to the observations already referred to, Messrs. PALMER and DALL made thirty-three exposures on the nebulæ contained in Professor KEELER'S programme, in the first half of 1901. Mr. PERRINE has since secured twenty-three exposures on these nebulæ, twenty-eight exposures on the Rumford variable star regions referred to above, and twenty-five exposures for miscellaneous purposes. Fellows

PALMER, STEBBINS, and CURTISS have ably assisted in the observations with the Crossley reflector.

A small slitless spectrograph was designed by Professor KEELER for use on faint objects with the Crossley reflector. It was completed on the day of his departure from the mountain. It was tested promptly by Messrs. CAMPBELL and PALMER, who found it necessary to use convex and concave quartz lenses in connection with the quartz prism, in order that the rays should be parallel when passing through the quartz prism. These changes were designed by Mr. PALMER, and the instrument was used extensively by him. He secured seventy spectrograms of the smaller planetary nebulæ and of other small objects. Many interesting facts resulted from these observations. I shall refer only to his success in photographing extremely faint spectra. A strong image of the spectrum of *Nova Cygni*, visual magnitude about 15.5, was obtained with ease. Successful exposures could probably be made on stars at least a magnitude fainter. His photograph of *Nova Cygni* demonstrates that the spectrum, which was nebular in 1877, has now become continuous, like that of the ordinary stars.

In addition to the observations of *Eros*, positions of asteroids *1900 GA*, *Ohio*, and *Palatia*, were determined by Mr. PALMER, from photographs taken with the Crossley reflector. Mr. HUSSEY secured eight observations of the asteroids *Minerva*, *Edna*, (440), and *Chicago*. Messrs. PALMER and CURTISS have recently secured photographs of several asteroids whose positions were requested, and the plates are being measured by Mr. CURTISS.

Mr. PERRINE has made 200 copies on glass of the eclipse photographs secured in India in 1898, in Georgia in 1900, and in Sumatra in 1901, for distribution to institutions, to societies, and to individual investigators taking special interest in this subject.

Three nights per week with the 36-inch equatorial have been devoted to the determination of the motions of the brighter stars in the line of sight, with the Mills spectrograph, during the past six years. The importance of line-of-sight investigations is attested by the fact that nearly all the powerful telescopes in the world are devoted at present largely to this purpose, though with varying degrees of success. The accu-

racy of the Lick Observatory determinations has steadily progressed until, for the stars containing fine lines, the probable error of a single determination of velocity is only about 0.25 kilometer.

To the list of fifteen spectroscopic binaries discovered prior to Director KEELER'S report of July 1, 1900, I desire to make twenty-three additions, as follows:—

β *Herculis*,
ξ *Ursæ Majoris*,
δ *Bootis*,
113 *Herculis*,
η *Andromedæ*,
π *Cephei*,
ξ *Piscium*,
ξ' *Ceti*,
δ *Equulei*,
ζ *Herculis*,
o *Andromedæ*,
γ *Canis Minoris*,
12 *Persei*,
93 *Leonis*,
β *Scuti*,
2 *Scuti*,
κ *Pegasi*,
31 *Cygni*,
τ *Persei*,
ϵ *Hydræ*,
α *Equulei*,
ϕ *Persei*,
η *Geminorum*.

These thirty-eight systems have been discovered since 1898. The satisfactory character of the results obtained with the Mills spectrograph, both in quantity and in quality, may be inferred from the fact that during the time these thirty-eight spectrographic binary systems were coming to light as a result of our work, only eight similar systems were announced by other observatories, and three of the eight were erroneous.

There is room for reference to only two of the stars on the above list: ζ *Herculis* is a short-period visual binary star, completing a revolution in about thirty-three years. The velocity of the principal star in the line of sight is slowly varying. κ *Pegasi* is one of the most interesting visual binaries known, period 11⅓ years. Until the discovery of the true period of δ *Equulei*, this was supposed to be the shortest period known. One of the components of κ *Pegasi* is a spectroscopic binary, having a period of only six days.

These binary systems have been discovered in the process of determining the velocities of about 350 stars; in this list of 350, previous observers had discovered three binaries. Without taking into account a list of several suspected binaries, it is apparent that of the brighter stars at least one in every seven or eight is attended by an invisible companion. When we consider that spectroscopic methods are at present capable of discovering only the larger variations, that very few stars of long periods have probably been advantageously observed as

yet, and that the velocity of our Sun, due to the orbital motions of the planets attending it, has a double amplitude of only two or three hundredths of a mile per second, there can be no doubt that the number of spectroscopic binaries must be very great. It is probable that the star unattended by dark companions will be found to be the exception rather than the rule.

Mr. WRIGHT has computed the orbit of the spectroscopic binary χ *Draconis*. Dr. REESE has computed the orbit of the spectroscopic binary *Capella*. Director CAMPBELL has computed the orbit of the variable star and spectroscopic binary ζ *Geminorum*. Dr. CRAWFORD has computed the orbit of the spectroscopic binary η *Pegasi*.

Dr. REESE, at my request, investigated the question of the diffraction of light of variable intensity, with special reference to the Mills spectrograph, as a guide in designing a more powerful instrument. He has likewise investigated the cause of the discrepancies between measures of spectrograms made with the violet end to the left, and with the violet end to the right, as a result of which he established the purely physiological cause of the discrepancy.

Dr. REESE has also designed the new mounting for the Mills spectrograph, referred to in a previous paragraph.

Photographs and preliminary measures of several hundred spectra have been made by Messrs. CAMPBELL, WRIGHT, and REESE; and a considerable number of definitive measures have been made.

In December, 1900, the Director utilized the results obtained for the velocities of 280 stars situated north of $-20°$ Declination in determining the speed and direction of the motion of the solar system through space. The result for the speed of the solar system comes out 19.9 kilometers, or 12.4 miles per second. The apex of the motion is in R.A. $277° 30'$, Declination $+20°$. The result for speed is very satisfactory. On account of the absence of material from the southern hemisphere, and the consequent irregular distribution of the observed stars over the sky, the direction assigned must be regarded as a rough approximation.

The average velocity in space of the 280 stars is 34.1 kilometers per second. The velocity of the solar system is therefore much less than the average for the other stars.

Another result of great interest is to the effect that the fainter stars are moving much more rapidly than the brighter ones.

The velocities of the stars have been observed to bear all values between sixty miles approach and sixty miles recession per second.

Investigations in this line have been shown to be practically endless, by our measurements of the velocity of the star *Groombridge 1830*. A special effort was made to measure its velocity, as this is the star which up to three years ago had the largest known proper motion. Its photographic magnitude is in the neighborhood of 7.5. The results obtained have shown that the observations may be extended by present methods to stars perhaps a magnitude fainter. Stars available for measurement are therefore numbered by thousands. As soon as half a dozen of the eight or ten great telescopes now engaged in this work have been made to produce accurate results, it will be highly desirable that the interested observatories arrange and carry out a scheme of coöperation on a large scale.

From Mt. Hamilton it is possible to secure the speeds of the stars between the North Pole and 30° South Declination. The stars in the quarter of the sky from 30° South to the South Pole remain unobserved. For many years it has been my desire to organize an expedition to the southern hemisphere for the purpose of measuring the velocity of these stars. The time for organizing this expedition seemed to have come in the winter of 1900. With the approval and indorsement of the President, the subject was brought to the attention of Mr. D. O. MILLS, who most generously offered to provide funds for constructing the instruments, for defraying traveling expenses, and for paying the salaries of the astronomers engaging in the work. It was decided to construct a reflecting telescope mounting to carry the extra 36¼-inch mirror that was in our possession, first cutting a hole through the center of the mirror in order that the Cassegrain form of mounting could be utilized. It was known that the mirror was of imperfect figure, and it was planned to have the JOHN A. BRASHEAR COMPANY refigure it after the hole had been cut. Unfortunately, in the process of cutting, the mirror broke in pieces on account of its enormous internal strains. This was not a misfortune, as Dr.

BRASHEAR reported that, on account of its very imperfect annealing, this piece of glass could never have been made to work well. A new mirror was ordered at once.

The telescope mounting, designed in general features by the Director, was brought to the mountain in December, 1901.

A powerful three-prism spectrograph, designed by the Director for use with the reflecting telescope, is completed. The delicate parts of the mounting were constructed by our instrument-maker, and the optical parts by the JOHN A. BRASHEAR COMPANY. Mr. WRIGHT has submitted the whole spectrograph to severe tests. Its performance appears to be superior even to that of the original Mills spectrograph. A modern steel dome was built for the expedition by the WARNER & SWASEY COMPANY, and was shipped to San Francisco on June 21st. The minor pieces of apparatus required have all been provided. It is planned to select a suitable observing-station in the vicinity of Santiago, Chile. It is confidently hoped that this work will be at least as fruitful as that carried on with the Mills spectrograph attached to the thirty-six-inch equatorial.

The Director wishes to make full acknowledgment of the enthusiastic support afforded him by the members of the Observatory staff. Every man has been ready to make the most of the opportunities supplied by the splendid instruments, by the unexcelled climatic conditions, and by the excellent policy inaugurated for the Observatory by the officers of the University of California.

W. W. CAMPBELL, *Director.*